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Briefing Report to Congressional Requesters

August 1986

NUCLEAR SAFETY

Comparison of DOE's Hanford N-Reactor With the Chernobyl Reactor

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Resources, Community, and
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The Honorable Mark O. Hatfield
Chairman, Committee on Appropriations
United States Senate

The Honorable James H. Weaver
Chairman, Subcommittee on
General Oversight, Northwest
Power, and Forest Management
Committee on Interior and
Insular Affairs
House of Representatives

This briefing report is in response to your requests for information on the Department of Energy's (DOE's) N-Reactor, located near Richland, Washington. As discussed with your respective offices, we gathered information on

--the similarities and differences in design and safety features of N-Reactor and the Soviet's reactor near Chernobyl,

--DOE's program to extend the life of N-Reactor, and

--emergency preparedness plans for N-Reactor.

On April 26, 1986, an accident occurred at a Soviet nuclear power plant near Chernobyl. While the exact sequence of events is not yet clear, it is evident that an explosion occurred, followed by a large release of radiation, indicating that there had been fuel melting. The realization that the Chernobyl reactor was moderated by graphite focused attention in the United States on DOE's N-Reactor, which is also graphite moderated. N-Reactor is operated by UNC Nuclear Industries under a contract with DOE. It produces plutonium, which is used in the production of nuclear weapons, and steam, which is sold to the local utility for electricity production.

In summary, we found that many differences exist between N-Reactor and the reactor near Chernobyl. One of the most significant of those differences involves the reactors' inherent physics responses to increases in coolant temperature--a situation that could occur during the initial stages of an accident. At the Chernobyl reactor, an increase in coolant temperature results in an increase in reactor power, a situation that could result in a run-away nuclear chain reaction. Many experts believe this situation was a critical element in the progression of the Chernobyl accident. The N-Reactor is quite different in this regard, with reactor power tending to decrease when coolant temperature increases, which in turn reduces the likelihood of a chain reaction.

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N-Reactor also has safety systems that apparently were not present on the Soviet reactor. These include a system to cool the graphite moderator and a backup, gravity-operated system to shut down the reactor.

Other characteristics of N-Reactor, however, do not appear to offer clear advantages when compared with the Chernobyl reactor. N-Reactor uses a metal form of uranium fuel, while the Chernobyl reactor uses an oxide form of uranium fuel. If an accident occurs and metal fuel comes into contact with coolant water, it creates more potentially explosive hydrogen than would be created by the oxide fuel. In this respect, the metal fuel is a disadvantage. On the other hand, metal fuel has an advantage in an accident situation because it stores less energy that must be removed by coolant. If coolant is not available, this energy could contribute to fuel melting.

Another characteristic is that N-Reactor uses once-through emergency cooling rather than a recirculating emergency cooling system like Chernobyl's. During an accident resulting in a loss of coolant at N-Reactor, the once-through cooling system draws water from a storage tank, and from the Columbia River when the tank is empty. This water passes through the reactor into a holding tank. If the holding tank fills, the radioactive water is stored in an outdoor, open pit. UNC Nuclear Industries is currently studying the possibility of migration of radioactive water from the pit to the Columbia River.

The Chernobyl reactor probably used some form of containment system to control steam pressures and the release of radioactive materials during an accident. We found that the overall safety of N-Reactor relies heavily on successful operation of a different type of system--a reactor confinement system. This system provides for steam pressure venting and filtering of airborne radioactive materials that may result from an accident. UNC Nuclear Industries' prior analyses have not found a credible accident scenario that would compromise the confinement system at N-Reactor and allow excessive amounts of radioactivity to escape to the environment. In the wake of the Chernobyl accident, UNC Nuclear Industries is analyzing accident scenarios that previously were not considered credible. (See section I.)

N-Reactor has been operating 3 years beyond its expected life, and many systems and components are deteriorating. Maintaining safe operations through the mid-1990's will require considerable upgrading and rehabilitation. To extend safe operation of N-Reactor beyond the year 2000, major renovations--costing as much as $1.2 billion--will be required. (See section II.)

Our work relating to emergency preparedness at N-Reactor revealed that DOE and its operating contractor are in compliance with 7 of 10 prior GAO recommendations. DOE was in partial compliance with two recommendations, involving the need for DOE review of emergency preparedness plans and programs. Although DOE reviews these plans and programs, the reviews are not conducted as often as we previously recommended. The recommendation

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that has not been implemented relates to an absence of state and local agencies' participation in N-Reactor site-wide emergency drills. DOE and state and local officials agree there is a need for joint participation in the drills; however, neither the state nor DOE budgets provide for funding of state or local participation. (See section III.)

We obtained the information presented in this briefing report primarily from DOE, UNC Nuclear Industries, and state and local government officials and documents. Information was also obtained from two DOE studies on the Safety of N-Reactor that were conducted in the post-Chernobyl time frame. While we believe the information contained in this report represents the best available information at the time of our review, information from the Soviet Union on the Chernobyl reactor and accident is still incomplete and, in some cases, has been conflicting. In addition, DOE has requested two additional studies on the safety of N-Reactor. A group of consultants are conducting a study of the design safety of N-Reactor. Also, the National Academy of Sciences plans to study the safety of N-Reactor later this year. When completed, these studies may provide additional information and new insights on the safety of N-Reactor. (See section IV.)

As requested, copies of this report will not be made available to other interested parties until 30 days after the date of its issuance or upon public release of its contents. If you have any questions or if we can be of further assistance, please feel free to contact me.

J. Dexter Peach
Director

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ABBREVIATIONS

AC	Alternating Current
DOE	Department of Energy
ES&H	Environment, Safety, and Health
FEMA	Federal Emergency Management Agency
GAO	General Accounting Office
MWd/kgU	megawatt days per kilogram Uranium
psi	pounds per square inch
psig	pounds per square inch gauge
WPPSS	Washington Public Power Supply System

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SECTION I

DESIGN AND SAFETY FEATURES OF N-REACTOR COMPARED WITH THE CHERNOBYL REACTOR

THE CHERNOBYL ACCIDENT

It is difficult to make a detailed analysis of the Chernobyl accident and compare the features of DOE's N-Reactor and the Soviet Chernobyl reactor because little verified information is available concerning the design of the Soviet reactor or the accident that occurred on April 26, 1986. The verified information available regarding the accident can be summarized briefly: there was an explosion resulting in a breach of the reactor building, and there was a large and extended release of radioactive materials, indicating that there had been extensive fuel melting.

While the Soviets have not released details of the accident progression, there is speculation among reactor experts that part of the accident involved a very rapid increase in the rate of the chain reaction. The possibility that this was part of the accident is supported by official Soviet statements that there was "a rapid rise in power from 6 to 50 percent in 10 seconds." In addition, Soviet scientists have published technical information regarding the physical characteristics of the Chernobyl reactor that make such an accident plausible.

There is little agreement among observers regarding the potential causes of the rapid power rise and the events that followed it. Various alternatives have been offered to explain how the accident was initiated, including experiments that may have lead to loss of coolant or fires that resulted in loss of electric power. There has also been a wide range of expert speculation regarding the events that followed the rise in power to account for the explosion, such as generation of large amounts of steam, generation of hydrogen from a reaction between the hot steam and the fuel cladding material, and the generation of combustible gases from a water-graphite reaction. None has been confirmed by Soviet officials; thus we will not address these issues.

COMPARISON OF CHERNOBYL AND N-REACTOR

N-Reactor has several obvious similarities to the Chernobyl reactor, including the use of graphite as the moderator and water in pressure tubes as the coolant. Numerous differences, however make it difficult to draw a one-to-one comparison between the two reactors, even if more information were available for the Chernobyl reactor. The remainder of this section discusses the similarities and differences of N-Reactor and the Chernobyl reactor in the following areas:

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--general information and site characteristics,

--moderator,

--coolant,

--fuel,

--reactor control,

--engineered safety systems, and

--confinement/containment systems.

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GENERAL INFORMATION AND SITE CHARACTERISTICS

	Chernobyl	Hanford N-Reactor
Location	Chernobyl, Ukraine U.S.S.R.	Richland, Washington U.S.A.
Population density	150,000-180,000 within 18 miles; 3.5-7 million within 100 miles	0 within 5-1/2 miles, 240 within 10 miles; 10,000 within 20 miles
Date of initial operation	1983	1963[a]
Power rating	1,000 megawatt electric, 3,140 megawatt thermal	860 megawatt electric, 4,000 megawatt thermal
Use	Electricity generation	Plutonium production for nuclear weapons; steam production for electricity generation as a byproduct
Basic configuration	Vertical pressure tubes, water cooled, graphite moderated	Horizontal pressure tubes, water cooled, graphite moderated

[a]Electricity generation began in 1966.

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General information

Both reactors are large nuclear plants, with the Chernobyl reactor producing slightly more electrical power and N-Reactor producing more thermal power. Both reactors have large inventories of radioactive materials in the core that could be dispersed in the event of an accident.

The two sites differ significantly in terms of the risk of radiation doses to a large number of people following an accident. The Chernobyl reactor is situated in a densely populated region, with more than 150,000 people within a 10-mile radius of the plant. In contrast, there are no permanent residents within 5-1/2 miles of N-Reactor, and only 240 people reside within 10 miles of the site.

Both reactors are cooled with ordinary ("light") water in more than 1,000 pressure tubes that encase the coolant and fuel. The pressure tubes are arranged parallel to one another in a large stack of graphite blocks that serves to slow down, or moderate, neutrons produced by the fission of uranium fuel, thus allowing a chain reaction to be sustained. This design differs from most commercial reactors in the United States, which use water as the moderator as well as the coolant and a single heavy steel pressure vessel rather than numerous pressure tubes.

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MODERATOR DATA

	Chernobyl	Hanford N-Reactor
Type	Graphite	Graphite
Amount	1,700 metric tons	1,980 metric tons
Operating temp.	1,382°F	950°F
Dedicated coolant system	No (heat conduction from graphite to coolant in pressure tubes)	Yes 640 cooling channels
Cover gas	Helium/nitrogen (inlet at bottom, outlet at top of reactor)	Helium (inlet and outlet at bottom of reactor)

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Moderator

Both reactors use graphite to moderate the chain reaction. Reactor graphite is a chemically pure form of carbon that is shaped into hard blocks, which are machined and drilled to allow pressure tubes, control rods, and other reactor instrumentation and equipment to pass through them. They are stacked to serve as support for the core components.

Graphite was used to moderate the first nuclear reactor in Chicago in 1942 and has since been considered a suitable material for moderating nuclear reactors (along with light water and heavy water).[1] Graphite is generally considered to have a safety advantage over water in that it can absorb a large amount of heat following a loss-of-coolant accident, thus delaying the onset of fuel melting and allowing time for safety systems or operator action to control the accident. For example, even if all cooling water were lost, the safety analysis report for N-Reactor indicates that the fuel would not begin melting for 7 minutes. In contrast, at a commercial light water reactor, fuel melting could begin within 10 to 30 seconds of a total loss of coolant.

The possibility of a graphite fire appears to be a risk, particularly in light of the published accounts of the events at Chernobyl. It has been speculated that a graphite fire, possibly ignited by hot or melted fuel, complicated recovery efforts and provided a heat source that contributed to the dispersion of radioactive materials to the environment. However, it has not been definitively established that the graphite ignited at Chernobyl, and some safety experts believe that this is unlikely.

Recent events have rekindled interest in an accident that occurred in a graphite-moderated reactor at Windscale, England, in 1957. The accident occurred during a maintenance procedure that was intended to restore the graphite to its condition before prolonged exposure to radiation and high temperatures. Coolant flow was deliberately restricted and the uranium fuel was used to heat up the graphite. Operator error and problems with instrumentation contributed to allowing the fuel to overheat and become exposed to the hot graphite. Although the chain reaction was shut down, the exposed fuel eventually caught fire and caused the failure and combustion of other fuel elements. The official inquiry by the British Government concluded that, while graphite could have ignited after the fuel had failed, it was extremely unlikely that a rapid release of energy from the graphite caused the fuel to fail.

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[1]A molecule of light water is made from one atom of oxygen and two atoms of the lightest form of hydrogen. By contrast, a molecule of heavy water is made with the form of hydrogen called deuterium, which has twice the mass of the lighter form of hydrogen.

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After the Windscale accident, experiments were performed at Hanford and Brookhaven National Laboratory to determine the extent of graphite combustibility. More recently, graphite tests have been conducted by UNC Nuclear Industries and an independent testing laboratory. The results of these experiments indicate that it is at least very difficult to ignite reactor-grade graphite, even when ample oxygen is available for combustion.

The graphite moderator block and associated systems at N-Reactor and at Chernobyl are designed to reduce the chance that oxygen (required for a fire) could come into contact with the graphite. The core is sealed to prevent oxygen ingress and inert gas is circulated through the graphite. Even if some oxygen did leak into the sealed graphite core, combustion gases would, in theory, eventually extinguish a graphite-oxygen reaction.

N-Reactor also is equipped with a cooling system for the graphite moderator that is separate from the fuel cooling system. This system is intended to keep the graphite cool and provide an additional source of heat removal that could limit fuel melting in the event that all other normal and emergency cooling fails to function. The only known heat-removal mechanism for the graphite in the Chernobyl reactor core is conductive heat transfer from the graphite to the pressure tubes carrying coolant for the fuel.

While experiments and experience cannot rule out the possibility of a graphite fire in a reactor, it appears that graphite is, at best, difficult to burn. UNC Nuclear Industries officials are confident that the systems in place at N-Reactor make it highly unlikely that a graphite fire could initiate an accident at N-Reactor.

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COOLANT DATA

	Chernobyl	Hanford N-Reactor
Type	Vertical pressure tubes, pressurized boiling light water	Horizontal pressure tubes, pressurized light water (no boiling)
Configuration	2 loops, 1,661 channels	6 loops (1 loop in reserve), 1,003 channels
Total coolant flow	37,500 metric tons/hr	38,500 metric tons/hr
Operating pressure		
Inlet	1,160 psig[a]	1,750 psig
Outlet	1,060 psig	1,600 psig
Operating temp.		
Inlet	518°F	400°F
Outlet	543°F	540°F

[a]Pounds per square inch gauge--a measure of the difference between actual pressure and atmospheric pressure.

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Coolant

Both reactors are cooled by light water. The water collects heat as it flows past the fuel in small-diameter pressure tubes and transfers the heat to turbine generators to produce electricity. The coolant temperatures in the two reactors are comparable. The pressures, however, are significantly different, with the reactor at Chernobyl operating at much lower pressure than N-Reactor. The higher pressure at N-Reactor prevents boiling throughout the core under normal operating conditions. In the Chernobyl reactor, the coolant begins boiling one-third of the distance along the fuel rod and continues to boil until it exits the reactor. This implies that the Chernobyl reactor operates with less margin to loss of cooling, or that the amount of additional heat required to boil off all the coolant is less at the Chernobyl reactor than at N-Reactor.

The two reactors also differ in the configuration of the coolant loops. At the Chernobyl reactor, two coolant loops split into 1,661 pressure tubes at the bottom of the core. Each of the two loops cools one-half of the core, independent of the operation of the other loop. According to Soviet technical papers, it is possible with this configuration that each half of the core could respond differently if a problem occurred in one of the two loops. For example, one of the accident scenarios hypothesized by Soviet scientists for the Chernobyl reactor is an inadvertent activation of one of its two emergency cooling systems, each of which supplies one-half the core. Injection of cool water into half the core can cause a change in power in that portion of the reactor. Automatic adjustments can cause a rise in power in the other half of the reactor.

At N-Reactor six coolant loops feed into a common manifold to allow mixing before the coolant enters the core. If the system operates as designed, UNC Nuclear Industries officials believe a problem with one coolant loop at N-Reactor would be more equally distributed throughout the core. Therefore, N-Reactor would be less likely to incur localized imbalances of the type that were possible in the Chernobyl reactor.

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FUEL DATA

	Chernobyl	Hanford N-Reactor
Type	Uranium dioxide	Uranium metal
Refueling mode	On-line	Off-line; refueled at 6-week intervals
Fuel element features	Fuel pellets inside zirconium alloy cladding, separated by a gap	2 concentrically nested tubes with a bonded zirconium alloy cladding
Configuration in core	18 pins/assembly; 2 assemblies per pressure tube	16-21 elements per channel, stacked end to end
Total uranium in core	189 metric tons	366 metric tons
Enrichment	2.0% U-235	0.95 - 1.25% U-235
Burnup	22.3 MWd/kgU[a]	1 MWd/kgU
Cladding temp.	540°F	525°F
Fuel temp.		
Average core	2,000°F	670°F
Centerline	2,500 - 3,000°F	700°F
Fuel melting temp.	3,300°F	1,995°F

[a]This abbreviation for fuel burnup is megawatt, days per kilogram uranium, a standard measure of how long fuel has been irradiated.

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Fuel

Both the Chernobyl reactor and N-Reactor use low-enriched uranium fuel, but there are few other similarities in fuel design. The Chernobyl fuel is an oxide form of uranium, comparable to the type of fuel used in commercial reactors in the United States, while N-Reactor uses a metallic form of uranium. One difference between the two fuel types is that oxide fuel does not react as readily with hot water as metal fuel does. The fuel-water interaction is a safety concern because it generates hydrogen, which could burn or explode if it is allowed to combine with oxygen. Both Chernobyl and N-Reactor are designed to prevent oxygen from coming into contact with the moderator or core internals. (See discussion of graphite moderator on p. 14.)

The two fuels also differ in their operating temperatures and melting points. Uranium oxide fuel melts at a much higher temperature than uranium metal fuel, but it also operates at a much higher temperature. While the Chernobyl reactor operated with fuel temperatures between 300°F and 800°F below its melting point, N-Reactor operates nearly 1,300°F below its melting point.

The difference in fuel form also affects the way an accident might progress. Metal fuel conducts heat efficiently from the center of the fuel, where it is hottest, to the outside where it can be cooled. Oxide fuel, on the other hand, is not as efficient a thermal conductor, and as a result, the center of oxide fuel is hotter than the center of metal fuel when the outside temperatures are the same. One implication of this is that an oxide core operating at the same coolant temperatures as a metal core will have much more energy stored in the fuel. This energy must be dissipated following an accident, even if the chain reaction is interrupted immediately. If cooling is not adequate, this energy could contribute to fuel and/or cladding failure.

In addition to differences in fuel design, there are also differences in the way the two reactors are refueled. The Chernobyl reactor was designed to be refueled while the reactor is operating in order to minimize interruptions in producing power. Some observers have speculated that the accident was initiated by an operator error during the refueling procedure. The N-Reactor is shut down for refueling, similar to the procedure followed at commercial nuclear power plants in the United States. DOE and UNC Nuclear Industries officials believe that this procedure limits the opportunities for mistakes leading to a serious accident during refueling.

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REACTOR CONTROL DATA

	Chernobyl	Hanford N-Reactor
Reactivity coefficients		
Moderator temp.	Positive	Positive
Water temp. (void)	Positive in most operating regimes	Negative
Fuel temp.	Negative	Negative
Primary shutdown system	211 boron-carbide rods, vertical	84 boron-carbide rods, horizontal
Secondary shutdown system	None	107 channels of boron-carbide balls, gravity-fed through vertical channels
Time to insert control rods to 75 percent	10 seconds	1.5 seconds

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Reactor control

Significant reactor control differences exist between N-Reactor and the Chernobyl reactor in areas such as (1) the reactors' inherent responses to changes in temperature and/or power and (2) design of the safety equipment that ensures rapid shutdown in the event of a malfunction.

Reactivity coefficients measure the inherent physical response--the change in the rate of the nuclear reaction--to changes in the temperatures of the graphite, coolant, and fuel. In graphite moderated reactors, the nuclear chain reaction tends to speed up as the temperature of the graphite increases (over a limited temperature range). In technical terms, this is referred to as a positive reactivity coefficient for moderator temperature. This is an undesirable feature of all graphite moderated reactors, but DOE and UNC Nuclear Industries officials consider it to be of limited significance because graphite temperatures change slowly.

At the Chernobyl reactor, an increase in the temperature of the coolant also causes the nuclear reaction to speed up, and overall the reactor tends to increase in power when the temperature rises. This response is referred to as a positive reactivity coefficient of coolant temperature. This has been a concern of Soviet scientists at reactors such as Chernobyl, and events have been identified that could require rapid operator action to prevent serious accidents from developing. Technical papers written by these Soviet scientists have addressed this issue, and changes have been made to the fuel design to lessen the effect. These changes have not, however, eliminated the basic problem--that the reactor does not inherently reduce the rate of the fission process as the power increases, but requires the operation of safety systems for shutdown. There has been widespread speculation that a rapid and uncontrolled rise in power occurred at Chernobyl and initiated a sequence of events that resulted in a steam explosion or the generation of hydrogen and its ultimate burning or explosion.

UNC Nuclear Industries officials informed us that an important part of the N-Reactor's design effort was to ensure an overall negative coefficient of reactivity. As reported in N-Reactor's safety analysis report and confirmed by measurements of the reactor, an increase in the coolant temperature at N-Reactor causes the rate of the fission reaction to decrease (i.e., the reactivity coefficient of coolant temperature is negative). Analysis presented in UNC Nuclear Industries' safety analysis report concludes that this effect is strong enough to overcome the undesirable response to increased graphite temperature, and that overall the chain reaction tends to shut itself down when any event causes temperatures to rise.

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Comparing the shutdown systems, the Chernobyl reactor had 211 safety rods that could be driven vertically into the core. These rods are composed of a boron compound, which absorbs neutrons and rapidly reduces the rate of the fission process. A similar system exists at N-Reactor which has safety rods that are arrayed horizontally rather than vertically. The safety system for shutdown at N-Reactor allows for rapid insertion, with 75 percent of the rod movement and nearly full shutdown occurring within 1.5 seconds. At the Chernobyl reactor, it appears that the same degree of insertion required about 10 seconds.

The literature on the Chernobyl reactor does not indicate that a secondary shutdown system existed. At N-Reactor, a completely independent and diverse secondary system is designed to provide full shutdown if the primary rod system fails to operate or operates too slowly. The secondary system allows boron balls to drop into vertical channels interspersed throughout the reactor, with no dependence on positive action from any mechanical component.

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ENGINEERED SAFETY SYSTEMS DATA

	Chernobyl	Hanford N-Reactor
Emergency core cooling	2 independent loops, each supplying one-half the core; gas pressurized water injection from 12 tanks; recirculation of water from suppression pools after tanks are drained	Dedicated diesel-driven pumps (2 of 3 required in each of two banks of pumps); manifold at inlet and outlet where 2 of 4 valves required to operate in each of 4 sets of valves Backup cooling provided by graphite and shield cooling system
Emergency power	1 dedicated diesel supplying AC power; 1 diesel shared with companion reactor	On-site steam turbines provide AC power for normal shutdown on loss of off-site power Dedicated diesel-driven pumps for emergency core cooling, fog spray, and graphite and shield cooling system

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Engineered safety systems

The Chernobyl reactor apparently had a dedicated emergency cooling system. As discussed in the section concerning reactor coolant, each of the two loops of the emergency cooling system is dedicated to cooling one-half the core. Initially, emergency water is drawn from 12 tanks pressurized by nitrogen. After the tanks are drained, coolant is recirculated through the core from suppression pools and other sources by pumps that can be powered by diesel generators.

N-Reactor has one loop of emergency cooling equipment that is completely separate from normal cooling paths. This loop is equipped with two sets of three pumps, and only two of three pumps in each set are required for full cooling of the core in emergency conditions. The N-Reactor system is based on once-through cooling rather than recirculation. The emergency cooling system initially draws from purified water that is stored in tanks on the site. When that supply is exhausted, water from the nearby Columbia River can be pumped through the reactor. Upon discharge from the reactor, the coolant is drained first into a holding tank, and when that is full, into an unlined earthen pit near the reactor. The N-Reactor once-through cooling mode is different from that used in U.S. power reactors, in which emergency water is recirculated within the reactor building. In congressional testimony the concern has been raised that the type of system used at N-Reactor could allow radioactive water to migrate toward the Columbia River. UNC Nuclear Industries officials have stated that the earthen pit has adequate capacity to accept once-through cooling water indefinitely. They are currently studying the capacity of the soil to filter out radioactive materials and the potential for restriction of the movement of water from the pit.

DOE's safety analysis report for N-Reactor (updated in 1978 by UNC Nuclear Industries) indicates that if emergency cooling can be activated as planned, there will be no fuel melting, even if the worst possible pipe break occurred in the primary system. Additional analysis was done to examine the effect of loss of emergency cooling in addition to loss of primary cooling, even though this accident is considered to be a remote possibility. (This analysis was performed to verify the satisfactory performance of the reactor in extreme circumstances.) Assuming that the graphite cooling system continues to operate and remove some of the heat from the fuel, the safety report concludes that no more than 32 percent of the fuel will melt in the first 25 minutes after primary and emergency coolant is lost. Subsequently, the graphite cooling system would be adequate to prevent additional fuel melting. If the confinement systems operate as designed, a small fraction of the radioactive gases and particulates generated in the accident would be released to the

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environment. The result of this hypothetical accident would be an off-site dose to the most exposed individual of less than 25 percent of DOE's allowable limit for a one-time accidental dose.

The scenario in which graphite cooling fails along with primary and emergency cooling has not yet been fully studied. Analysts at N-Reactor are in the process of calculating the effect of such an accident on the core and determining the resulting dose to the off-site population.

A source of emergency power is important because monitoring and control instrumentation are needed long after the chain reaction in a reactor is shut down. In addition, a continuing need exists to remove heat after shutdown since reactors produce significant amounts of residual heat for hours. The Chernobyl reactor apparently was equipped with on-site diesel generators to supply AC power in the event of a failure of off-site power. It is reported that the output from one of two available diesels was adequate to supply emergency cooling needs.

N-Reactor's emergency power system is structured differently. All emergency AC power needs can be met by on-site boilers that are fueled with fuel oil, in combination with a turbine-generator set to convert the steam from the boilers into electricity. The most important instrumentation and controls are backed up with battery supplies that are designed to provide power to ensure safe shutdown. The systems that require power for pumping water into the reactor or confinement areas, such as emergency core cooling, graphite moderator and shield cooling, and a sprinkler-type system known as a fog spray, can be powered by individual, direct-drive diesels at each of the pumps.

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CONFINEMENT/CONTAINMENT SYSTEMS DATA

	Chernobyl	Hanford N-Reactor
Filter/vent system	None reported	Initial steam venting, controlled filtered release thereafter (steam and gases pass through moisture separators, particulate filters, and charcoal filters)
Pressure suppression/ fission product retention	2 pools of water below the reactor for pressure suppression; sprinkler system for post-accident heat removal	Fog spray (2 inches of water per minute); 1 of 2 standby pumps required, which can be powered by standby diesels
Pressure boundary		
Maximum	26 psig for the reactor compartment;	5 psig
Minimum	57 psig for the piping compartment	-2 psig

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Confinement/containment systems

Confinement and containment systems are designed to prevent radioactive materials, which could be released after a severe accident, from being dispersed directly into the environment. The operation of these systems is necessary to limit off-site radiation doses to acceptable levels. Extensive testing and analysis is done to ensure that, if required, the system will perform as designed. If containment/confinement fails following a severe accident, serious off-site consequences can be expected.

Containment systems, which probably existed in some form at the Chernobyl reactor and which are common at commercial reactors, differ from the confinement system used at N-Reactor. Containment systems are designed to prevent all the steam and nearly all the radioactive materials from escaping the reactor building. There are many different types of containment designs, each relying on different combinations of pressure suppression and pressure retention. One common pressure suppression technique is to reduce the energy of the steam, and hence reduce the pressure that the building must be able to withstand. This can be done by diverting steam through a pool of water or through a bank of ice. Pressure retention is generally handled by constructing a reactor building of reinforced steel and concrete so that it can withstand the maximum pressures expected after a severe accident, such as a large break in coolant piping.

The Chernobyl reactor was equipped with two pools of water located under the reactor. They were intended to quench steam releases in an accident and remove some of the radioactive materials in the steam. The reactor also was equipped with a sprinkler system, which was intended to remove the heat from steam released after an accident. The Chernobyl reactor building was probably designed to withstand some increased level of pressure. Information developed by U.S. analysts indicates that various systems were enclosed in separate compartments, which were designed to withstand different pressures. For example, the reactor compartment might have been able to withstand as much as 26 psig pressure, and the coolant piping compartments might have been designed to withstand 57 psig. The Chernobyl design probably did not incorporate many of the features that are required for containment systems on U.S. commercial reactors, but it appears to have incorporated some pressure suppression and retention features.

Confinement systems differ from containment systems in that they are designed to prevent and/or release--rather than contain--pressure buildup from an accident. One approach is to allow for an initial burst of non-radioactive steam to be released directly to the environment. Another approach is to incorporate pressure suppression features within the confinement building. These

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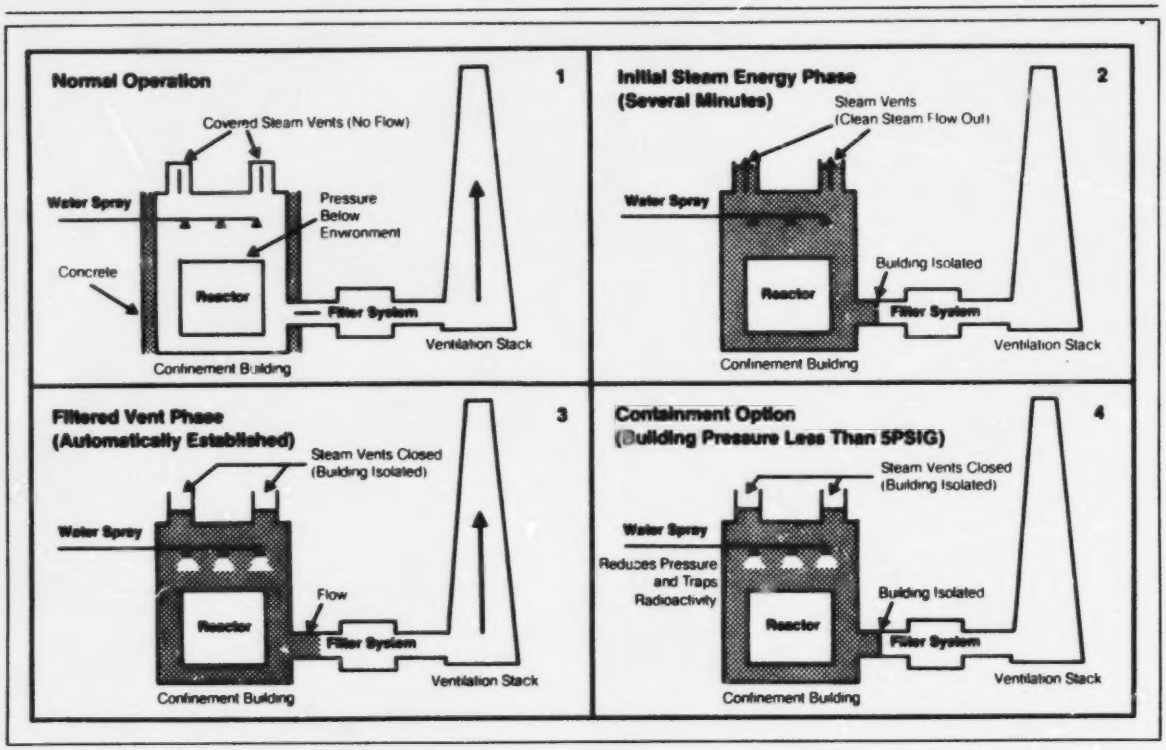
FIGURE I.1

N-REACTOR CONFINEMENT SYSTEM IN OPERATION



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suppression features can be similar to those discussed for containment systems. After the initial release of steam, confinement systems are designed to prevent additional pressure buildup by filtering radioactive gases before they are released from the building.

The confinement building at N-Reactor is designed to withstand pressures in the range of -2 psig to 5 psig and to vent to the atmosphere the initial burst of steam that could occur after certain accidents. The safety analysis report indicates that cladding on the fuel would not fail for at least 7 minutes after the worst accident; thus, the steam initially would contain no significant levels of radioactive materials. At N-Reactor the confinement system was designed to vent steam directly to the atmosphere during this period. After the pressure is reduced to low levels (usually within 2 minutes), the steam vents are designed to close automatically and remain closed indefinitely.

After the steam vents close, another N-Reactor system is designed to reduce pressures and remove heat arising from additional generation of gases and steam. The fog spray system is designed to operate automatically when pressures rise too high. The system sprays cool water at 2 inches per minute throughout the reactor building. Analysis of the fog spray system in the N-Reactor safety analysis report shows that it is adequate to keep pressures within acceptable limits if other systems operate as designed. Since gases and steam continue to be generated as the accident progresses, they must be released from the building to prevent overpressurization. This is designed to be handled by filtering the gases and steam through banks of charcoal filters to absorb radioactive iodine and through metal filters to retain radioactive particulates.

Questions have been raised in congressional hearings about the possibility of more than one large burst of steam occurring after a major accident at N-Reactor. DOE has identified no accident sequences that produce multiple releases of steam that could compromise the confinement system. However, DOE stated that if such an accident were possible, the subsequent pressure increases might occur after the steam vents to the environment had closed and the confinement building could potentially become overpressurized. If this sequence were to occur, unfiltered paths to the environment might be opened up. Analysts at N-Reactor are currently reexamining all potential accident scenarios to ensure that none could compromise the confinement systems.

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SECTION II

SAFETY IMPLICATIONS OF EXTENDING

THE N-REACTOR'S LIFE

N-Reactor was built in 1963 with an expected life of 20 years. N-Reactor has operated for 23 years and, according to DOE and UNC Nuclear Industries officials, many systems and components have aged and are deteriorating. This section provides information on two DOE programs aimed at extending the life of the N-Reactor. They are the Productivity Retention Program and the Production Assurance Program.

PRODUCTIVITY RETENTION PROGRAM

The Productivity Retention Program is directed toward ensuring N-Reactor's continued operation in a safe and reliable manner through the mid-1990's. The program addresses near-term problems that require budget action starting in fiscal year 1986 and continuing through fiscal year 1994. Aging systems and components have been identified and prioritized for replacement, repair, or modification. While the primary objective is to ensure reliable operation into the 1990's, these renovations are also prerequisite to any efforts to extend the reactor's life beyond the year 2000.

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TABLE II.1

COST AND SCHEDULE FOR PRODUCTIVITY RETENTION PROGRAM

Program projects	Start (fiscal years)	Complete (fiscal years)	Estimated cost (in millions)
Foster Wheeler boiler retubing	1986	1988	$ 5.2
V-11 valve rehabilitation	1986	1988	17.0
Water sample conditioning and analytical equipment upgrade	1987	1990	4.6
Drive turbine oil supply and control system improvements	1987	1989	2.5
Flow monitor system upgrades	1987	1988	5.8
Primary pump rehabilitation	1988	1990	3.0
Electrical distribution upgrades	1988	1990	9.3
Automated refueling system	1988	1991	9.5
Safety instrumentation upgrade	1989	1993	36.0
Alternate AC electrical power source	1991	1994	7.0
Total			$99.9

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Foster Wheeler boiler retubing

The Foster Wheeler boiler is one of two boiler systems that provide standby steam to drive the reactor coolant pumps during reactor startup, shutdown, and reduced coolant flow conditions. The standby steam also is required to power the emergency electricity generator in the event of an electrical system outage.

Problem

The piping inside the boiler has corroded to the extent that five failures have occurred since January 1, 1986 and more are expected. Recent tests by the operating contractor showed that 209 tubes or about 18 percent of the tubes tested were at or below minimum acceptable thickness.

Possible consequences

The standby steam is needed to provide sufficient steam for 1/2 hour after an emergency shutdown of the reactor. If the Foster Wheeler boiler should fail, another boiler system is available to provide steam.

Ongoing/planned actions

DOE plans to replace the piping in the Foster Wheeler boiler. Preliminary work required prior to actual replacement is underway.

V-11 valve rehabilitation

Each of N-Reactor's 1,003 pressure tubes contains a V-11 valve. The 2-inch valves are manually operated and are normally in the open position. When the old fuel is extracted and replaced with new fuel, the valves are closed to reduce the flow of water through the pressure tubes that are being refueled.

Problem

The internal part of the valves contains a disc that reduces the flow of coolant when in the closed position. UNC Nuclear Industries officials informed us that these discs are deteriorating and must be replaced because the weakened disc could break and cause a partial blockage in a process tube. In addition, a broken piece could lodge in the pressure tube and damage the fuel.

Possible consequences

If a blockage of coolant to a pressure tube occurs during operation, the reactor is designed to automatically shut down. UNC Nuclear Industries officials stated it is not clear whether or

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not a pressure tube rupture would result from fuel failure or overheating. However, UNC Nuclear Industries has performed an analysis of a single pressure tube rupture accident, and the consequences were determined to be minimal from a safety standpoint.

Ongoing/planned actions

DOE plans to refurbish or replace all V-11 valves. Preliminary work required prior to actual replacement is underway.

Water sample conditioning and analytical equipment upgrade

To preserve component life and minimize system corrosion, the chemistry of the water in the reactor's cooling system must remain within established limits. To ensure this, cooling water is to be sampled and analyzed during reactor operation from 96 different locations. The water conditioning equipment controls the sampling stream temperature and pressure.

Problem

According to UNC Nuclear Industries officials, the in-line analytical equipment for radioactive and nonradioactive samples is inoperable, thus requiring manual sampling methods. In addition, the temperature and pressure control equipment for nonradioactive samples is in disrepair. Water chemistry limits are exceeded about 12 times per month. This results in accelerated corrosion of the cooling system.

Possible consequences

The primary issue is the reactor personnel safety risk, due to manual extraction of water samples from the high pressure and high temperature sample stream. In addition, manual sampling causes delay in availability of results.

Ongoing/planned actions

DOE plans to upgrade the water sample conditioning and analytical equipment beginning in fiscal year 1987.

Drive turbine oil supply and control system improvements

The primary coolant pumps supply cooling water to 1,003 pressure tubes during reactor operations. These pumps are driven by steam turbines, which receive steam from the reactor. The speed of the steam turbines, and consequently the amount of coolant, is regulated by a speed control system. The turbine

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shafts, which extend from the turbine to the coolant pumps, contain several bearings that are supplied oil by electrically driven pumps.

Problem

Reactor outages have resulted from turbine speed oscillations caused by the worn and degraded speed control systems, and the oil supply system has failed and resulted in bearing damage and reactor outages. In addition, the electric oil pumps that oil the shaft bearings are totally dependent on electric power.

Possible consequences

Deficiencies in the speed control systems could result in shutdown of the turbine and the reactor. Total loss of electricity to the oil pumps would damage the turbine shaft and bearings and result in a loss of the primary coolant pumps. If this occurs, the reactor would have to be shut down and the emergency core cooling system would be activated.

Ongoing/planned actions

DOE plans to replace the speed control systems and supplement the shaft oiling system to provide a supply of oil independent of electric power. These renovations are scheduled to begin in fiscal year 1987.

Flow monitor system upgrades

The flow monitoring system measures the flow of coolant through each of the 1,003 pressure tubes and automatically shuts down the reactor if the flow does not meet established parameters.

Problem

Several of the sensing tubes or lines that measure the flow on each pressure tube have begun to show signs of stress corrosion cracking. One line has failed to date and the situation is worsening. By fiscal year 1988 five failures per year are expected.

Possible consequences

According to UNC Nuclear Industries officials, an increase in the failure rate of the flow monitoring system will increase reactor shutdowns and outage time, and result in loss of electric generation and production of nuclear materials.

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Ongoing/planned actions

DOE plans to begin a program during fiscal year 1987 to replace the sensing lines.

Primary pump rehabilitation

There are six primary pumps that provide coolant to 1,003 pressure tubes.

Problem

Because of pump deterioration, overhauls are required every 2 years, as opposed to a normal 5-year schedule. Five of the six pumps are required to be in service to run the reactor at the planned power rate. However, because of pump deterioration, the reactor has operated with four pumps at a reduced power level on several occasions.

Possible consequences

Loss of primary coolant pump availability results in reactor shutdowns, reduced operating power levels, and lost production.

Ongoing/planned actions

DOE plans to begin a pump rehabilitation program in fiscal year 1988.

Electrical distribution upgrades

The electrical distribution system consists of the primary electrical wires and connectors, which distribute power to the entire reactor system.

Problem

Electrical wire has failed, causing reactor outages while wires were being replaced; connectors have corroded and grounded out; and motors used to activate valves on the steam bypass system are deteriorated. Replacement motors cannot be obtained because they are no longer procurable. In addition, the graphite shield cooling system pumps are becoming increasingly inefficient because of worn parts and deterioration.

Possible consequences

Failures in the electrical wire, connectors, motors, and pumps included in this project could result in reliance on other safety systems to compensate for the loss of the normal power system. For example, a failure in the primary wiring system could result in start-up of the emergency diesel generators.

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Ongoing/planned actions

Beginning in fiscal year 1988, DOE plans to upgrade the electrical distribution system and replace the electric motors and graphite shield cooling pumps.

Automated refueling system

N-Reactor refueling is currently performed manually.

Problem

When the pressure tube end caps are removed to allow for refueling, radioactive water is released.

Possible consequences

Increased chances exist for reactor personnel exposures to radiation and the loss of large amounts of primary cooling water.

Ongoing/planned actions

Beginning in fiscal year 1988, this project will provide a robot-type method of refueling the reactor instead of manual refueling. This project will also decrease the time required for refueling.

Safety instrumentation upgrade

The reactor safety instrumentation has tens of thousands of electronic components, such as diodes, transistors, resistors, and amplifiers, which allow reactor operators to safely monitor various reactor systems.

Problem

General industrial experience indicates the life for the electrical components contained in the reactor safety system to be about 20 years. Failures have already occurred in capacitors on the reactor coolant flow monitoring system. Although these have been replaced, it is believed to be an indication of overall degradation of such components.

Possible consequences

There are thousands of electrical components that could fail and each failure could have a different consequence. However, DOE and UNC Nuclear Industries officials informed us that all critical safety systems operate on a "fail safe" mode--if the instruments fail, the systems operate automatically and the reactor is shut down.

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Ongoing/planned actions

DOE plans to replace portions of the reactor safety instrumentation beginning in fiscal year 1989.

Alternate AC electrical power source

At present, N-Reactor has two AC power supplies. One is off-site (Bonneville Power Administration) and the other is on-site (a steam turbine-driven electric generator).

Problem

During reactor outages, the steam turbine-driven electric generator is taken out of service but must remain in a standby status. This leaves only one electric source, the off-site AC power supply. Since two AC power supplies are required to be in service to simultaneously test or inspect certain safety systems, the steam turbine-driven electric generator and boilers, which provide the steam during shutdown, cannot be tested, inspected, or repaired because they are required to remain in a standby status.

Possible consequences

While the present two AC power supply systems are adequate for safe reactor operation, an additional source will enhance safety and provide more flexibility for system testing and repairs.

Ongoing/planned actions

Beginning in 1991, DOE plans to establish a third electric source.

PRODUCTION ASSURANCE PROGRAM

The Production Assurance Program is directed toward major systems and components that will need renovation or replacement starting in the early 1990's and ensure reactor operations through the year 2000. The objective of the program is to eventually renovate or replace all major systems or components. This program would essentially renew the reactor.

Reactor components are being monitored in an effort to project their remaining useful life and provide options for extending the life of the reactor. Depending on the option(s) selected, the program could cost anywhere from $370 million for operability to the year 2000 to $1.2 billion to ensure operability to the year 2025.

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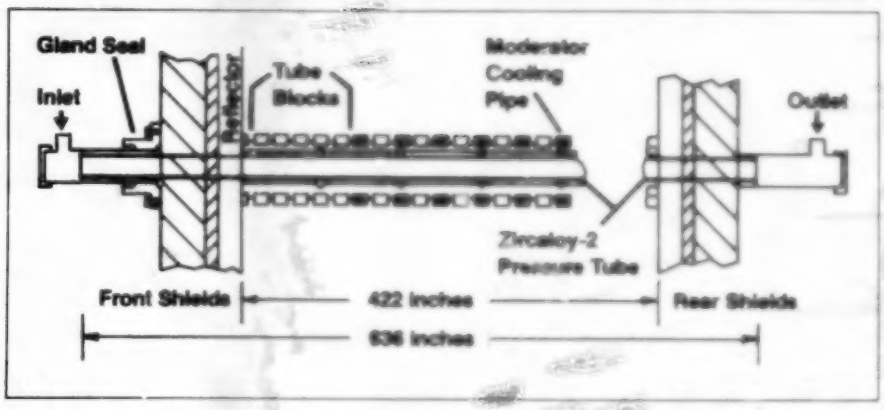
FIGURE II.1

SIDE VIEW OF N-REACTOR PRESSURE

TUBE AND COOLANT FLOW



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Pressure tube integrity

The pressure tubes contain the fuel elements and extend horizontally through the reactor. Each of the 1,003 tubes is connected at ends with piping, which allows cooling water to flow through the tube. The water is pressurized and becomes heated as it flows through the tubes. The extracted hot water produces steam for electric generation; then it is cooled and returned to the tubes.

Problem

The tubes are becoming brittle from neutron bombardment, making them more likely to fracture or break. However, no known cracks or leaks have occurred. According to UNC Nuclear Industries officials, brittle fracture limits for the tubes will not be exceeded before the mid-1990's.

Possible consequences

A single tube rupture would not be a significant accident because the flow monitoring system is designed to initiate an automatic reactor shutdown. However, there is a possibility that fuel damage could occur in the failed tube.

Future response

DOE plans to expand inspection, testing, and analysis to provide confidence in projections. Approximately five tubes are scheduled to be replaced beginning in fiscal year 1987. Replacement of all tubes will be necessary if the reactor is required to operate past the 1990's.

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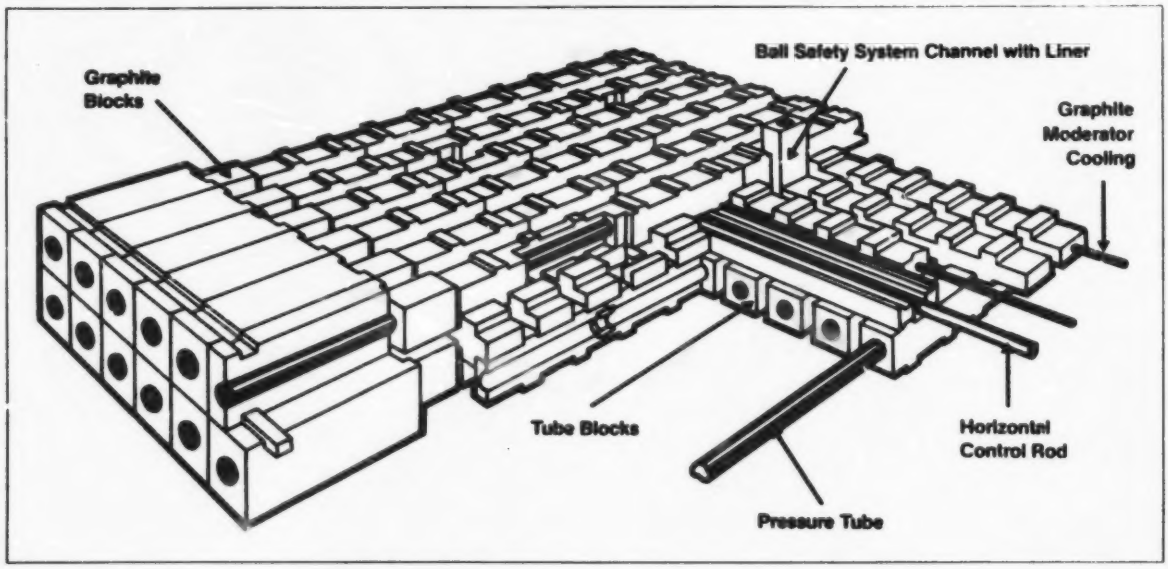
FIGURE II.2

SIDE VIEW OF N-REACTOR CORE AND COMPONENTS



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Graphite and control systems

N-Reactor is constructed of graphite blocks in a lattice-type structure approximately 33 feet high, 33 feet wide, and 39 feet long. The graphite contains major components of the reactor, including the pressure tubes, horizontal boron control rods, vertical ball channels, and graphite cooling tubes. The reactor's safe operation is dependent upon these components, which penetrate and extend through the graphite blocks. According to UNC Nuclear Industries officials, in this respect, if major movement occurred in the graphite structure, many of the systems could become ineffective.

Problem

The graphite structure is monitored for distortion, oxidation, and irradiation effects. Since 1984 the structure has been vertically expanding and, according to UNC Nuclear Industries officials, the effects of the distortion will accelerate as the graphite continues to expand. The structure is expected to expand 5 inches by 1995, at which time it will begin to contact the overhead shielding, causing structural damage.

Possible consequences

Graphite expansion is a slow process and routinely monitored. Sudden expansion is not expected. If the graphite was allowed to expand to the point of contacting the overhead shield, the reactor would shut down.

Future response

An enhanced graphite distortion surveillance program will monitor reactor core conditions and predict future rate of condition changes. If growth continues at the expected rate, UNC Nuclear Industries officials believe that periodic maintenance on the channels (overboring, etc.) will have to be performed. However, by 1995 the graphite is expected to have expanded to such an extent that control rod channels, process tube channels, and the graphite cooling system would become distorted. Consequently, the graphite would require rehabilitation or replacement.

Shield, gas, and graphite cooling systems

The primary shield surrounds the reactor core. The shield is sealed and provides containment for helium gas, which covers the reactor to prevent oxidation of the graphite. An inner-thermal shield containing boron-10 is used to absorb neutrons.

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The graphite cooling system is made up of 640 tubes routed through the graphite blocks. The tubes circulate water continuously to remove heat from the graphite.

Problem

The 1,003 pressure tubes extend through the shield at the front and back ends of the reactor and were initially designed to move freely through a sleeve to accommodate tube expansion caused by heat and pressure. The sleeves have failed and do not provide free movement. The pressure tube expansion has moved the shields out about 0.8 inch. The possibility exists for structural damage and seal rupturing. It is not certain how far the shields can move before the seal ruptures.

Since operations began in 1963, three leaks have occurred in the graphite cooling system. The boron shield is expected to function properly beyond the year 2000.

Possible consequences

Consequences of an accident resulting from seal rupture or a graphite cooling system leak could be minimized by the safety systems available. Movement of the end shields eventually would result in structural damage.

Future response

Correction of the pressure tube problem is planned for 1986 by stretching the tubes in such a way that the tubes will pull the primary shield back to its original position. By the end of 1986, upgraded gas system controls and instrumentation will be in operation to provide better monitoring of the integrity of the seal around the shield. In addition, a comprehensive surveillance and assessment program will be initiated during fiscal year 1986 to ensure that the graphite cooling syster is properly maintained.

Refueling program

Fuel elements, which are 26 inches long, are inserted into the pressure tubes using hydraulic pressure. As the new element is inserted in the front end of the tube, it forces the old element out the back of the tube.

Problem

Pressure tubes have become distorted because of graphite expansion, and this has increased friction and drag between the element and the pressure tube.

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Possible consequences

Because the reactor is always shut down during refueling and the sealing caps at both ends of the pressure tube are removed, there are no safety consequences.

Future response

Pressure tube distortion is monitored to ensure maintenance of refueling capabilities. In addition, a 17-inch fuel element is being designed and its use should provide refueling capabilities through 1990 without corrective measures, such as tube replacement, boring the graphite blocks, etc. Also, a diagnostic program is underway to determine whether drag force, physical interferences, and related factors are within acceptable limits.

Use of flux flattening

Flux flattening is a modified reactor operating approach developed to slow the rate of graphite distortion. Flux flattening involves careful fuel management and moderate control rod movement to more evenly spread the level of neutron activity throughout the reactor core. Currently, neutron activity--and graphite distortion--is highest in the center of the core.

Problem

The graphite is expected to expand to the overhead shield by 1995 and cause structural damage.

Possible consequences

According to an analysis performed by UNC Nuclear Industries officials, flux flattening will slow the expansion rate of the graphite and prevent it from contacting the overhead shield before the late 1990's (as opposed to 1995). At present, there are no known safety risks.

Future response

DOE plans to convert the center of the core to a flux flattening region and implement an in-core monitoring capability to observe flux flattening and identify any related safety issues.

Balance of plant evaluation

This effort is directed toward eventually evaluating all systems or components outside the shield that encases the reactor. The objective is to develop a strategy to extend the life of the systems or components to support operation of the

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reactor into the 2000's. Many safety-related systems are included in the evaluation, including the boron ball safety system, primary piping, and safety-critical valves.

Problem

Recommendations, as a result of the evaluation, were made to modify or repair most of the systems or components. The evaluation has thus far addressed 17 separate systems or components. Some of the systems have caused minor problems requiring repairs, and others have caused more significant problems requiring reactor shutdown.

Possible consequences

The consequences of an accident resulting from failure of the various systems range from minimal to complete reliance on secondary systems and engineered safety systems.

Future response

Recommendations stemming from the evaluation of the systems will become action items, which are arranged in order of priority for implementation.

Reactor safety and environmental evaluations

The reactor safety evaluation was made to reverify the reactor's ability to withstand two types of accidents: a seismic event and a pressure tube rupture. The evaluation was made to consider the effects that graphite distortion and pressure tube embrittlement might have on the accidents.

The environmental evaluation was made to determine whether planned activities of the Production Assurance Program would require compliance with the National Environmental Policy Act.

Problem

These evaluations were performed because of the effect that geometric changes in the reactor graphite stack may have on the structural integrity of the reactor. For example, some of the graphite blocks have cracked, and block movement has caused locking keys or slots to break or shear off.

Possible consequences

The safety evaluation disclosed that, in the event of either accident, the reactor core would retain its structural integrity,

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required cooling components would retain their functional integrity, and the boron ball and control rod safety systems would remain operable.

The environmental evaluation concluded that formal documentation required under the National Environmental Policy Act would not be required until major reactor rehabilitation work, scheduled for the 1990's, began.

Future response

On the basis of the evaluation's results, no rehabilitation is needed now for continued operation of the reactor.

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SECTION III

STATUS OF DOE EFFORTS TO IMPLEMENT PRIOR GAO EMERGENCY PREPAREDNESS RECOMMENDATIONS

If a nuclear accident occurs and the safety systems break down and fail to control and contain the accident, detailed emergency preparedness plans covering the duties of the responsible organizations, and programs to rapidly and effectively implement the plans, are crucial to bringing the accident under control as well as minimizing the danger to public health and safety. The nuclear accident at Chernobyl reaffirms that the greatest public health hazard from a nuclear accident is the potential exposure of the population and the environment to releases of radioactive material. The events occurring after the Chernobyl accident indicate that a breakdown occurred with systems for protecting the public in areas such as radiation dosage assessment, communication and coordination, notification, and sheltering and evacuation.

Minimizing the hazard of radiation exposure to people and the environment requires the prompt and correct responses of the organizations responsible for emergency preparedness. For the Hanford site these organizations are the DOE Richland Operations Office (hereafter referred to as Richland), which manages the Hanford site; contractors that operate the nuclear facilities and provide support to the operators and to Richland;[1] the Washington Public Power Supply System (WPPSS), a public utility that operates a commercial nuclear reactor at Hanford; and state, local, and other federal agencies.

In three previous reports, we made recommendations to improve emergency preparedness plans and the programs to implement the plans at nuclear facilities, and determined what actions DOE had taken to implement our recommendations. In two of the previous reports we made 10 recommendations to DOE, which involved consolidating emergency preparedness functions and providing guidance to DOE field offices and contractors; requiring reviews and evaluations of the emergency preparedness plans and programs of field offices and contractors; and increasing support to off-site federal, state, and local agencies with emergency preparedness responsibilities.

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[1]Major contractors at Hanford with emergency preparedness responsibilities are UNC Nuclear Industries, which operates the N-Reactor; Rockwell Hanford Operations; Battelle Memorial Institute; Hanford Environmental Health Foundation; Westinghouse Hanford Company; J.A. Jones Construction Company; and Kaiser Engineers Hanford Company.

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In a 1979 report, we reviewed emergency preparedness plans and programs for commercial and government-owned nuclear facilities and made five recommendations to DOE to correct weaknesses in these plans and programs.[2] In a 1981 report we reexamined these areas to determine what actions DOE had taken to correct these weaknesses.[3] At that time we could not find any record that DOE had instructed its organizations to implement our recommendations. In addition, we found that the DOE field offices had done little to correct the deficiencies. We made five additional recommendations in that report and also recommended that DOE correct the weaknesses identified in our 1979 report. In a 1983 report we noted that although problems still existed in DOE's emergency preparedness program, DOE was taking steps to correct the weaknesses we identified in our 1979 and 1981 reports.[4]

As part of our response to this request, we followed up on all prior recommendations to determine whether the weaknesses we identified have been corrected. Specifically, we reviewed the recommendations as they affect the adequacy of emergency preparedness at the Hanford site. The status of the 10 recommendations is discussed in the following section.

1. Consolidate the policymaking, coordinating, and appraisal functions into one organizational unit that is at a level of authority higher than the units responsible for implementing established policy.

When we made this recommendation in 1981, DOE's emergency preparedness responsibilities were fragmented, not clearly defined, and not always carried out. In addition, the safety and health organization at DOE headquarters did not have sufficient authority to carry out its responsibilities because of its relatively low position in DOE's organization.

DOE has taken steps to increase the independence of its safety and health activities, including its emergency preparedness program. DOE created the Office of Assistant Secretary for Environment, Safety, and Health (ES&H), which reports directly to the Under Secretary of Energy. The ES&H office is on the same level in DOE's organization as the program offices, which are responsible for operations at DOE's nuclear facilities. In addition to elevating the organizational level of the safety,

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[2]Areas Around Nuclear Facilities Should Be Better Prepared For Radiological Emergencies (EMD-78-110, March 30, 1979).

[3]Better Oversight Needed For Safety and Health Activities At DOE's Nuclear Facilities (EMD-81-108, Aug. 4, 1981).

[4]DOE's Safety And Health Oversight Program At Nuclear Facilities Could Be Strengthened (GAO/RCED-84-50, Nov. 30, 1983).

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health, and emergency preparedness functions, this organizational change consolidated the emergency preparedness policymaking, coordination, and appraisal functions for DOE's nuclear facilities into one office.

DOE is also taking other actions to increase the authority of the ES&H office. According to ES&H officials, they are revising internal operating orders to increase ES&H oversight of DOE operations. A significant change involves requiring ES&H concurrence with program offices in activities such as the start-up of a new facility or significant modifications to older DOE facilities. In addition, these orders would permit the ES&H office to recommend suspension of operations at a facility because of undue safety risks. With the issuance of these orders--which is expected in August 1986--ES&H officials believe their office will become the focal point for safety and health activities in DOE.

2. Develop DOE emergency preparedness requirements that define DOE and contractor responsibilities and describe emergency preparedness criteria.

When we made this recommendation in our 1981 report, DOE's emergency preparedness program was based on a cancelled directive. Each field office was free to determine its own level of emergency preparedness and we found that those levels varied greatly between the offices and their nuclear facilities.

Our 1983 report recognized that DOE had issued orders providing for coordination among DOE headquarters and field offices and providing direction to these offices in planning for and responding to radiological emergencies. The orders delineate the specific responsibilities and authorities of headquarters and field offices and require that DOE field offices and their contractors that operate their nuclear facilities develop (1) site-specific plans and procedures for radiological emergencies and (2) comprehensive plans and procedures to protect on-site personnel, the general public, and the environment in the event of a radiological release.

These DOE orders remain in effect and discussions with Richland officials indicate that they are aware of their responsibilities and the responsibilities of their contractors under these orders. The Richland emergency preparedness plan has been reviewed by DOE headquarters officials, who concluded that the plan meets DOE emergency preparedness criteria. Further, DOE headquarters has concurred with the plan with one exception, which does not affect the adequacy of the Hanford site's emergency preparedness. This exception concerns the protective response guides adopted in the Pichland plan. Richland adopted guides used by the Nuclear Regulatory Commission because it wanted to use the same guides that the state and local agencies use for responding to a nuclear emergency at the WPPSS commercial nuclear reactor.

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Discussions with contractor officials also indicate they are cognizant of the DOE orders and their responsibilities under them.

3. Require a complete headquarter's review of the site's emergency preparedness plans at least every 2 years.

When we made this recommendation in our 1979 report, DOE headquarters officials were reviewing only those activities that related to their particular program areas. However, reviewing a specific activity, rather than the site plans as a whole, increases the potential for gaps in emergency response planning and public protection.

According to ES&H officials, DOE headquarters has generally had no direct role in reviewing the emergency preparedness plans of the contractors at Hanford. Instead, ES&H has tasked Richland with the responsibility for reviewing the operating contractors' emergency preparedness plans. Richland officials review the contractors' plans as part of its appraisals of the contractors' emergency preparedness programs, which are conducted every 24-36 months. They also review the contractor's plans as part of the site-wide exercises to test the contractors' emergency preparedness programs.

ES&H officials reviewed the emergency preparedness plans of the contractor responsible for operating the N-Reactor as part of its July 1986 safety appraisal of the reactor. This appraisal is part of the 1985 initiatives ordered by the Secretary of Energy to improve safety at DOE's nuclear facilities.

The July 1986 appraisal made specific recommendations to correct weaknesses in the contractor's plans and programs and their implementation. The major recommendations made in the appraisal to correct weaknesses follow:

--Upgrade the emergency response capability of N-Reactor's emergency control room, emergency control center (located in an on-site trailer), and alternate emergency control center (located in an off-site building).

--Upgrade the emergency control room and emergency control center to ensure their habitability during an emergency.

--Improve the training for shift managers in their role as emergency director.

--Revise emergency plans to define clearly the authorities and responsibilities of managerial personnel throughout an emergency.

The appraisal noted that contractor officials already were in the process of upgrading the control room when this recommendation

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was made. ES&H officials expect to follow up on all these recommendations to ensure that corrective action is taken. DOE orders require that the contractor provide, within 30 days, written responses that explain the corrective actions planned to address the recommendations. ES&H officials said they expect to receive the contractor's responses in August 1986. ES&H officials said they plan to visit the N-Reactor facility by the end of 1986 to verify compliance by the contractor with the corrective actions planned.

4. Require annual appraisals of field offices' and contractors' emergency preparedness programs.

This recommendation was made in 1981 because DOE headquarters efforts were ineffective for ensuring that emergency preparedness programs were being implemented by field offices and contractors. Program appraisals are needed so DOE can ensure that its field offices and contractors were properly interpreting and implementing DOE's emergency preparedness policy and criteria and that the emergency plans would work in an emergency.

According to DOE headquarters and Richland officials, headquarters has not performed an appraisal of Richland and its contractors' emergency preparedness programs since December 1983. Headquarters and Richland officials said they had expected that ES&H would appraise the Richland program later this year. However, according to ES&H officials, they have delayed this appraisal until next year because of the current Chernobyl-related reviews and audits underway at Hanford. They said that they would not be able to fully appraise the Richland program and how its program affects the Hanford facilities at this time because many key personnel both at headquarters and Richland are involved in these reviews and audits.

Richland has not performed annual appraisals of the emergency preparedness program of the contractor that operates the N-Reactor at Hanford. Richland completed an emergency preparedness program appraisal of this contractor in 1982 and did not appraise the program again until 1985. The 1985 appraisal noted that one of the observations in the 1982 appraisal has not been satisfied and included it for follow-up in the latest appraisal. The observation was still open because the contractor had not provided documentation to support its contention that the observation had been satisfied.

The latest appraisal concluded that the technical elements of the contractor's emergency preparedness program provided for a "very good rating." However, because of the lack of information, cooperation, and assistance provided by the contractor, the contractor received a satisfactory rating from Richland. Richland noted that the completion of the appraisal was delayed by several months because of the difficulty in receiving input from the contractor.

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Some of the deficiencies noted in the appraisal follow:

--The contractor is not updating and revising its emergency plan consistent with program changes.

--The co ctor plans and policy manual lack consistency.

--The contractor drill program has not been implemented and internal drill deficiencies are not being tracked.

--No formal system exists to track follow-up actions on deficiencies noted in internal reviews and audits.

Richland officials followed up on the findings and observations in the appraisal in September and October 1985 to ensure that corrective action is being taken. The contractor's response in January 1986 indicates that all relevant actions to correct Richland's findings and observations have been completed or plans are underway to correct them. Richland officials said they have verified that the contractor has satisfied all but two of the findings and expect to verify those by the end of this summer.

5. Perform annual comprehensive (site-wide) radiological emergency response drills that test the emergency response plans against realistic simulated accident conditions.[5]

We made this recommendation in our 1979 report because radiological emergencies could reasonably be expected to affect more than one facility at a site, requiring a site-wide response. In addition, we concluded that site-wide exercises are necessary to ensure that all on-site facilities with emergency preparedness responsibilities can respond to a site-wide emergency.

Our 1981 report recognized that of the DOE field offices reviewed, only Richland was complying with this recommendation. Richland tasks the contractors at its Hanford site with conducting annual comprehensive (site-wide) radiological emergency response exercises. (According to Richland officials, contractors participate in the exercises and also observe and critique the actions of other contractors during the exercises. The contractors do not critique their own performance.) The last exercise, in March 1986, tested the adequacy of the involved organizations to respond to both a radiological emergency and a breach of security. The exercise was conducted under realistic simulated accident and security conditions. Richland, while participating in the exercise, was observed and critiqued by other contractors who participated in the exercise.

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[5]Richland defines a drill as a test at only one facility usually involving one contractor. An exercise is a test at one or more facilities involving one or more contractors.

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According to Richland officials, they are in the process of compiling the findings and observations prepared by the contractors. Until they complete this task they cannot determine the major deficiencies of the contractors who participated in the exercise. They expect to notify the contractors of their deficiencies by early August. Richland will then follow up within 30 days to determine what corrective actions have been planned or taken by the contractors to correct the deficiencies.

6. Independently review and evaluate (nonsite-wide) contractor drills on a regular basis.

This recommendation was intended to provide assurance that contractors are appropriately interpreting and implementing DOE emergency preparedness policy and criteria. In our 1983 report we recognized that Richland was complying with this recommendation.

Richland continues to comply with this recommendation. Richland requires that exercises (nonsite-wide) be conducted on at least a quarterly basis. Since July 1, 1985, contractors have been involved in approximately seven exercises both on- and off-site of Hanford. (Contractors provide off-site radiological emergency support to federal, state, and local agencies and to operators of commercial nuclear power plants.) Richland officials observe these exercises and critique the performance of the participants. Written responses to the critiques and corrective actions, if applicable, are required of the contractors. The Richland office tracks and follows up on the corrective actions taken. Some of the deficiencies noted in these seven exercises were delays in notification of responsible personnel and operational failure of equipment. The follow-up critiques indicate these deficiencies are being corrected.

7. Develop formal and explicit agreements between facility operators and state and local government agencies having emergency preparedness responsibilities that delineate the roles and responsibilities of each party during an emergency.

In our 1979 report we found that credible nuclear accidents could result in radiological releases outside facility boundaries; however, DOE facilities' response plans did not ensure that state and local organizations would be notified.

In our 1981 report we recognized that Richland was complying with this recommendation by means of three signed agreements with state and local agencies. Since our 1981 report, Richland has also signed 10 more agreements with cognizant local, state, and federal agencies, public utilities, and local hospitals that delineate clearly the roles and responsibilities of each party during an emergency. Richland has included these 13 agreements as an appendix to its emergency preparedness plan.

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8. Provide support necessary to carry out responsibilities delegated by the Federal Emergency Management Agency to improve emergency preparedness around nuclear facilities.

The Federal Emergency Management Agency (FEMA) is responsible for leading and coordinating emergency response planning for nuclear accidents. In 1981 FEMA relied on DOE to assist in fulfilling its responsibilities. In our 1983 report we noted that Richland was performing the tasks assigned to it by FEMA.

According to Richland and FEMA officials, Richland continues to perform the tasks assigned by FEMA that concern emergency preparedness activities involving Hanford. Richland has issued emergency preparedness plans and procedures for the Hanford facility and assisted state and local governments in preparing their plans. Richland assisted the state and counties in preparing their plans and ensured that each plan follows the same basic format and includes the same clearly defined roles for each party during an emergency. It has supported FEMA in its efforts to assist state and local governments in their emergency preparedness planning at Hanford. It has also assisted FEMA in (1) developing planning guidance for state and local governments, (2) developing state and local governments' plans, and (3) reviewing their plans. In addition, Richland continues to provide representation to and support for the federal effort, headed by FEMA, in overseeing emergency preparedness activities involving commercial nuclear facilities.

9. Encourage state and local emergency response agencies to participate in site-wide emergency drills.

We made this recommendation in our 1979 report because credible nuclear accidents with off-site radiological releases could threaten the public health. Therefore, off-site agencies must be prepared to coordinate their emergency responses with on-site agencies to ensure that the public is adequately protected.

State and local emergency response agencies have not participated in site-wide emergency exercises involving DOE's nuclear facilities at Hanford. (State and local emergency response agencies do participate in site-wide exercises involving the WPPSS commercial nuclear reactor at Hanford.) Richland and state and local officials contend that the state and county agencies do not have adequate funding to allow them to participate in site-wide exercises. The Washington State budget provides funding for state and local government participation in exercises involving commercial nuclear facilities only, not DOE nuclear facilities.

Richland officials said they want the state and local agencies to participate in their site-wide exercises. They have requested DOE headquarters to provide direct funding for this

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purpose but have not been provided the funding. In 1981 the state of Washington requested DOE funding for this purpose but also was denied. DOE denied funding in both cases because the DOE budget does not provide for direct funding of state and local emergency preparedness organizations. However, DOE headquarters said that it would provide assistance to states through use of DOE services, technical help, and space provided at its emergency control centers.

10. Inform the public of potential hazards, emergency actions planned, and protective measures to take in the event of a radiological emergency.

At the time we made this recommendation in our 1979 report, DOE did not believe its facilities posed a threat to the public and had not pursued emergency planning. DOE also was reluctant to inform the public because national security could be jeopardized, and they did not want to unnecessarily raise public fear or create a target for terrorist activities.

In our 1981 report we recognized that Richland had begun to implement this recommendation by preparing a handbook for distribution to the public. Since that time Richland has taken additional actions to implement this recommendation. In cooperation with the state of Washington and the three counties surrounding Hanford, Richland has been informing the off-site public of the potential hazards of a radiological emergency, the emergency actions planned by Richland and the state and local governments, and the protective actions to take in the event of a radiological emergency. Richland has accomplished these objectives through personal interaction with the public; funding the preparation of pamphlets and other documents that have been distributed to the public by local officials; and distribution of communication equipment to the public. Richland's specific actions in this regard include the following:

--Richland officials or one of the contractors at Hanford attend public presentations (conducted by the state, county, or WPPSS) on the hazards of radiation and actions to take in the event of a radiological emergency. In addition, Richland and its contractors attend training sessions and emergency drills at local hospitals. Richland officials also participate in evacuation training drills at local schools.

--Richland has paid for the printing of documents for distribution in nearby counties, including calendars that detail the consequences of an accident and actions to take during a radiological emergency and various brochures and pamphlets that explain protective actions to take during an emergency.

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--Richland has provided communication equipment directly to citizens who would be most affected by a radiological emergency at N-Reactor. It installed special, dedicated phones in the houses of the 35 families who live within 10 miles of the N-Reactor to notify them of an emergency and advise them of the emergency responses they should take.

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SECTION IV

SCOPE AND METHODOLOGY OF OUR REVIEW

Our work involved gathering information on

--the similarities and differences in design and safety features of N-Reactor and the Soviet's reactor near Chernobyl,

--DOE's program to extend the life of N-Reactor, and

--emergency preparedness plans for N-Reactor.

Information presented in this report pertaining to the accident at Chernobyl was obtained through discussions with DOE, UNC Nuclear Industries, and Battelle Northwest Laboratory officials. (Battelle is collecting information on the accident for DOE.) We also monitored news articles related to the accident. To compare the Chernobyl reactor with DOE's N-Reactor, we obtained design, safety, and operating data for each reactor. Information on the Chernobyl reactor was obtained from translated Soviet technical papers, news articles, and from documents obtained from and discussions held with DOE, UNC Nuclear Industries, and Battelle Northwest Laboratory officials. An effort has been made to present the best available data for the Chernobyl reactor and accident. However, it should be recognized that information emanating from the Soviet Union on the Chernobyl reactor and accident is still incomplete and, in some cases, has been conflicting.

We obtained information on the design, safety features, and operating characteristics of N-Reactor from discussions with and documents from DOE and UNC Nuclear Industries officials. Visual verification of some of these features was obtained during a visit to N-Reactor. We obtained information on safety features and N-Reactor's operation under various accident scenarios from the safety analysis report prepared for N-Reactor (updated by the UNC Nuclear Industries in 1978).

We also reviewed two studies conducted by DOE headquarters' ES&H office. One of these studies reviewed the adequacy of N-Reactor's confinement system and the possibility of a graphite fire at N-Reactor. The second study involved the review of design and operational safety and emergency preparedness at N-Reactor. DOE has requested two additional studies of the design and safety of N-Reactor. One of these studies is being conducted by a panel of nuclear experts and is expected to result in several reports later this year. The second study, to be conducted by the National Academy of Sciences, has not yet begun.

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Information on the extended life program was obtained from discussions with DOE and UNC Nuclear Industries officials and documents obtained from these officials. We also reviewed budgetary documents pertaining to the extended life program.

To obtain information on emergency preparedness at N-Reactor, we reviewed N-Reactor's compliance with 10 recommendations made in prior GAO reports. To ascertain compliance with those recommendations, we reviewed emergency preparedness plans, appraisals of those plans, and emergency drill critiques. We held discussions with DOE and UNC Nuclear Industries officials and visited N-Reactor's emergency center. We also held discussions with emergency preparedness officials from local counties, Washington State, and Oregon State. We discussed DOE's plans and role in emergency preparedness with a Federal Emergency Management Agency official.

We obtained oral comments on a draft of this briefing report from DOE and UNC Nuclear Industries officials. These officials generally agreed with the contents of the document. Where appropriate, factual changes were incorporated.

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